

IN THE CLAIMS

LISTING OF CLAIMS

1 Claim 1 (withdrawn): A method of tracking the orientation of a sensor, the
2 method comprising:

- 3 a) measuring an angular velocity of the sensor to generate angular
4 rate values;
5 b) integrating the angular rate values;
6 c) normalizing the integrated angular rate values to produce an
7 estimate of sensor orientation;
8 d) measuring a magnetic field vector to generate local magnetic
9 field vector values;
10 e) measuring an acceleration vector to generate local gravity vector
11 values; and
12 f) correcting the estimate of sensor orientation using the local
13 magnetic field vector and local gravity vector.

1 Claim 2 (withdrawn): A method of tracking as in Claim 1 wherein correcting
2 the estimate of sensor orientation using the local magnetic field vector and
3 local gravity vector comprises:

- 4 g) determining a measurement vector from the local magnetic field
5 vector values and the local gravity vector values;
6 h) calculating a computed measurement vector from the estimate of
7 sensor orientation;
8 i) comparing the measurement vector with the computed
9 measurement vector to generate an error vector that defines a criterion
10 function;
11 j) performing a mathematical operation that results in the
12 minimization of the criterion function and outputs an error estimate;
13 k) integrating the error estimate;
14 l) normalizing the integrated error estimate to produce a new
15 estimate of sensor orientation; and

16 m) repeating steps a)-m), wherein the new estimate of sensor
17 orientation is used for h), calculating a computed measurement vector until
18 tracking is no longer desired.

1 Claim 3 (withdrawn): The method of Claim 2 wherein the operation of j),
2 performing a mathematical operation that results in the minimization of the
3 criterion function comprises minimizing the criterion function without
4 calculating the criterion function.

1 Claim 4 (withdrawn): The method of Claim 2 wherein the operation of j),
2 performing a mathematical operation that results in the minimization of the
3 criterion function includes implementing a partial correction step to
4 compensate for measurement error.

1 Claim 5 (currently amended): ~~The method of Claim 4 wherein implementing~~
2 ~~the partial correction step to compensate for measurement error is~~
3 ~~supplemented by using a weighted least squares regression to emphasize~~
4 ~~more reliable measurements with respect to less reliable measurements.~~

5 A method of tracking the orientation of a sensor, the method comprising:

6 _____ a) measuring an angular velocity of the sensor to generate angular
7 rate values;

8 _____ b) integrating the angular rate values;

9 _____ c) normalizing the integrated angular rate values to produce an
10 estimate of sensor orientation;

11 _____ d) measuring a magnetic field vector to generate local magnetic
12 field vector values;

13 _____ e) measuring an acceleration vector to generate local gravity vector
14 values; and

15 _____ f) correcting the estimate of sensor orientation using the local
16 magnetic field vector and local gravity vector.

17 _____ wherein correcting the estimate of sensor orientation using the local

magnetic field vector and local gravity vector comprises:

g) determining a measurement vector from the local magnetic field vector values and the local gravity vector values;

h) calculating a computed measurement vector from the estimate of sensor orientation;

i) comparing the measurement vector with the computed measurement vector to generate an error vector that defines a criterion function;

j) performing a mathematical operation that results in the minimization of the criterion function and outputs an error estimate;

wherein the operation of performing a mathematical operation that results in the minimization of the criterion function includes implementing a partial correction step to compensate for measurement error;

wherein implementing the partial correction step to compensate for measurement error is supplemented by using a weighted least squares regression to emphasize more reliable measurements with respect to less reliable measurements;

k) integrating the error estimate;

l) normalizing the integrated error estimate to produce a new estimate of sensor orientation; and

m) repeating steps a)-m), wherein the new estimate of sensor orientation is used for h), calculating a computed measurement vector until tracking is no longer desired.

Claims 6 (withdrawn): The method of Claim 2 wherein the operation of j), performing a mathematical operation that results in the minimization of the criterion function comprises using time weighted filtering.

Claim 7 (withdrawn): The method of Claim 2 wherein the operation of g), performing a mathematical operation that results in the minimization of the criterion function comprises using a Gauss-Newton iteration.

1 Claim 8 (withdrawn): A method of tracking the orientation of a sensor, the
2 method comprising:

- 3 a) measuring an angular velocity of the sensor to generate an
4 angular rate quaternion;
5 b) integrating the angular rate quaternion;
6 c) normalizing the integrated angular rate quaternion to produce an
7 estimated sensor orientation quaternion; and
8 d) measuring a magnetic field vector to generate local magnetic
9 field vector values;
10 e) measuring an acceleration vector to generate local gravity vector
11 values;
12 f) correcting the estimated sensor orientation quaternion using the
13 local magnetic field vector and local gravity vector.

1 Claim 9 (withdrawn): A method of tracking as in Claim 8 wherein correcting
2 the estimated sensor orientation quaternion using the local magnetic field
3 vector and local gravity vector comprises:

- 4 g) determining a measurement vector from the local magnetic field
5 vector values and the local gravity vector values;
6 h) calculating a computed measurement vector from the estimated
7 sensor orientation quaternion;
8 i) comparing the measurement vector with the computed
9 measurement vector to generate an error vector that defines a criterion
10 function;
11 j) performing a mathematical operation that results in the
12 minimization of the criterion function and outputs an error estimate
13 quaternion;
14 k) integrating the error estimate quaternion;
15 l) normalizing the integrated error estimate quaternion to produce a
16 new estimated sensor orientation quaternion; and

17 m) repeating steps a)-m), wherein the new estimated sensor
18 orientation quaternion is used for h), calculating a computed measurement
19 vector.

1 Claim 10 (withdrawn): The method of Claim 9 wherein the operation of j),
2 performing a mathematical operation that results in the minimization of the
3 criterion function comprises minimizing the criterion function without
4 calculating the criterion function.

1 Claim 11 (withdrawn): The method of Claim 9 wherein the operation of j),
2 performing a mathematical operation that results in the minimization of the
3 criterion function includes implementing a partial correction step to
4 compensate for measurement error.

1 Claim 12 (currently amended): ~~The method of Claim 10 wherein~~
2 ~~implementing the partial correction step to compensate for measurement error~~
3 ~~is supplemented by using a weighted least squares regression to emphasize~~
4 ~~more reliable measurements with respect to less reliable measurements~~

5 A method of tracking the orientation of a sensor, the method comprising:

- 6 a) measuring an angular velocity of the sensor to generate an
7 angular rate quaternion;
8 b) integrating the angular rate quaternion;
9 c) normalizing the integrated angular rate quaternion to produce an
10 estimated sensor orientation quaternion; and
11 d) measuring a magnetic field vector to generate local magnetic
12 field vector values;
13 e) measuring an acceleration vector to generate local gravity vector
14 values;
15 f) correcting the estimated sensor orientation quaternion using the
16 local magnetic field vector and local gravity vector;
17 wherein correcting the estimated sensor orientation quaternion

18 using the local magnetic field vector and local gravity vector comprises:
19 g) determining a measurement vector from the local magnetic field
20 vector values and the local gravity vector values;
21 h) calculating a computed measurement vector from the estimated
22 sensor orientation quaternion;
23 i) comparing the measurement vector with the computed
24 measurement vector to generate an error vector that defines a criterion
25 function;
26 j) performing a mathematical operation that results in the
27 minimization of the criterion function and outputs an error estimate
28 quaternion;
29 wherein the operation of performing a mathematical operation that
30 results in the minimization of the criterion function comprises minimizing the
31 criterion function without calculating the criterion function;
32 wherein the operation of performing a mathematical operation that
33 results in the minimization of the criterion function includes implementing a
34 partial correction step to compensate for measurement error;
35 wherein implementing the partial correction step to compensate for
36 measurement error is supplemented by using a weighted least squares
37 regression to emphasize more reliable measurements with respect to less
38 reliable measurements;
39 k) integrating the error estimate quaternion;
40 l) normalizing the integrated error estimate quaternion to produce a
41 new estimated sensor orientation quaternion; and
42 m) repeating steps a)-m), wherein the new estimated sensor
43 orientation quaternion is used for h), calculating a computed measurement
44 vector.

1 Claims 13 (withdrawn): The method of Claim 9 wherein the operation of j),
2 performing a mathematical operation that results in the minimization of the
3 criterion function comprises using time weighted filtering.

1 Claim 14 (withdrawn): The method of Claim 9 wherein the operation of g),
2 performing a mathematical operation that results in the minimization of the
3 criterion function comprises using a Gauss-Newton iteration.

1 Claim 15 (withdrawn): A method of tracking the orientation of a sensor, the
2 method comprising:

- 3 a) providing a starting estimate of sensor orientation;
- 4 b) measuring a magnetic field vector to generate local magnetic
5 field vector values;
- 6 c) measuring an acceleration vector to generate local gravity vector
7 values;
- 8 d) determining a measurement vector from the local magnetic field
9 vector values and the local gravity vector values;
- 10 e) calculating a computed measurement vector from the estimate of
11 sensor orientation;
- 12 f) comparing the measurement vector with the computed
13 measurement vector to generate an error vector that defines a criterion
14 function;
- 15 g) performing a mathematical operation that results in the
16 minimization of the criterion function and outputs an error estimate;
- 17 h) integrating the error estimate;
- 18 i) normalizing the integrated error estimate to produce a new
19 estimate of sensor orientation; and
- 20 j) repeating steps a)-j), wherein the new estimate of sensor
21 orientation is used for e), calculating a computed measurement vector.

1 Claim 16 (withdrawn): The method of Claim 15 wherein each new estimate
2 of sensor orientation is output as a sensor orientation signal.

1 Claim 17 (withdrawn): The method of Claim 15 wherein the operation of g),
2 performing a mathematical operation that results in the minimization of the

3 criterion function comprises minimizing the criterion function without
4 calculating the criterion function.

1 Claim 18 (withdrawn): The method of Claim 15 wherein the operation of g),
2 performing a mathematical operation that results in the minimization of the
3 criterion function includes implementing a partial correction step to
4 compensate for measurement error.

1 Claim 19 (currently amended): ~~The method of Claim 18 wherein~~
2 ~~implementing the partial correction step to compensate for measurement error~~
3 ~~is supplemented by using a weighted least squares regression to emphasize~~
4 ~~more reliable measurements with respect to less reliable measurements.~~

5 A method of tracking the orientation of a sensor, the method comprising:

6 a) providing a starting estimate of sensor orientation;

7 b) measuring a magnetic field vector to generate local magnetic
8 field vector values;

9 c) measuring an acceleration vector to generate local gravity vector
10 values;

11 d) determining a measurement vector from the local magnetic field
12 vector values and the local gravity vector values;

13 e) calculating a computed measurement vector from the estimate of
14 sensor orientation;

15 f) comparing the measurement vector with the computed
16 measurement vector to generate an error vector that defines a criterion
17 function;

18 g) performing a mathematical operation that results in the
19 minimization of the criterion function and outputs an error estimate;

20 wherein the operation of performing a mathematical operation that
21 results in the minimization of the criterion function includes implementing a
22 partial correction step to compensate for measurement error;

23 wherein implementing the partial correction step to compensate for

24 measurement error is supplemented by using a weighted least squares
25 regression to emphasize more reliable measurements with respect to less
26 reliable measurements;

27 h) integrating the error estimate;

28 i) normalizing the integrated error estimate to produce a new
29 estimate of sensor orientation; and

30 j) repeating steps a)-j), wherein the new estimate of sensor
31 orientation is used for e), calculating a computed measurement vector.

1 Claims 20 (withdrawn): The method of Claim 15 wherein the operation of g),
2 performing a mathematical operation that results in the minimization of the
3 criterion function comprises using time weighted filtering.

1 Claim 21 (withdrawn): The method of Claim 15 wherein the operation of g),
2 performing a mathematical operation that results in the minimization of the
3 criterion function comprises using a Gauss-Newton iteration.

1 Claim 22 (withdrawn): The method of Claim 15 wherein the operation of g),
2 performing a mathematical operation that results in the minimization of the
3 criterion function and outputs an error estimate includes:

4 measuring an angular velocity of the sensor to generate angular rate
5 values;

6 integrating the angular rate values;

7 normalizing the integrated angular rate values to produce an estimate of
8 sensor orientation derived from the angular rate values; and

9 using the estimate of sensor orientation derived from the angular rate
10 values to correct for time lag.

1 Claim 23 (withdrawn): A method of tracking the orientation of a sensor, the
2 method comprising:

3 a) providing a starting estimate of sensor orientation quaternion;

- 4 b) measuring a magnetic field vector to generate local magnetic
5 field vector values;
- 6 c) measuring an acceleration vector to generate local gravity vector
7 values;
- 8 d) determining a measurement vector from the local magnetic field
9 vector values and the local gravity vector values;
- 10 e) calculating a computed measurement vector from the estimate of
11 sensor orientation, using quaternion mathematics;
- 12 f) comparing the measurement vector with the computed
13 measurement vector to generate an 6x1 error vector that defines a criterion
14 function;
- 15 g) performing a mathematical operation that results in the
16 minimization of the criterion function and outputs a 4x1 quaternion error
17 estimate;
- 18 h) integrating the quaternion error estimate; and
- 19 i) normalizing the integrated quaternion error estimate to produce a
20 new estimated sensor orientation quaternion;
- 21 j) repeating steps a)-j), wherein the new estimated sensor
22 orientation quaternion is used for e), calculating a computed measurement
23 vector.

1 Claim 24 (withdrawn): The method of Claim 23 wherein the operation of g),
2 performing a mathematical operation that results in the minimization of the
3 criterion function and outputs a 4x1 quaternion error estimate comprises
4 minimizing the criterion function without calculating the criterion function.

1 Claim 25 (withdrawn): The method of Claim 23 wherein the operation of g),
2 performing a mathematical operation that results in the minimization of the
3 criterion function and outputs a 4x1 quaternion error estimate comprises
4 multiplying the 6x1 error vector by the function $[XX]^{-1}X^T$.

1 Claim 26 (withdrawn): The method of Claim 23 wherein the operation of g),
2 performing a mathematical operation that results in the minimization of the
3 criterion function and outputs a 4x1 quaternion error estimate further includes
4 implementing a partial correction step to compensate for measurement error.

1 Claim 27 (withdrawn): The method of Claim 23 wherein the operation of g),
2 performing a mathematical operation that results in the minimization of the
3 criterion function and outputs a 4x1 quaternion error estimate comprises using
4 a time weighted filtering system.

1 Claim 28 (withdrawn): The method of Claim 23 wherein the operation of g),
2 performing a mathematical operation that results in the minimization of the
3 criterion function and outputs a 4x1 quaternion error estimate comprises using
4 a Gauss-Newton iteration.

1 Claim 29 (currently amended). ~~The method of Claim 26 wherein~~
2 ~~implementing the partial correction step to compensate for measurement error~~
3 ~~is supplemented by using a weighted least squares regression to emphasize~~
4 ~~more reliable measurements with respect to less reliable measurements~~
5 A method of tracking the orientation of a sensor, the method comprising:
6 a) providing a starting estimate of sensor orientation quaternion;
7 b) measuring a magnetic field vector to generate local magnetic
8 field vector values;
9 c) measuring an acceleration vector to generate local gravity vector
10 values;
11 d) determining a measurement vector from the local magnetic field
12 vector values and the local gravity vector values;
13 e) calculating a computed measurement vector from the estimate of
14 sensor orientation, using quaternion mathematics;
15 f) comparing the measurement vector with the computed
16 measurement vector to generate an 6x1 error vector that defines a criterion

17 function;

18 g) performing a mathematical operation that results in the
19 minimization of the criterion function and outputs a 4x1 quaternion error
20 estimate;

21 wherein the operation of g), performing a mathematical operation that
22 results in the minimization of the criterion function and outputs a 4x1
23 quaternion error estimate further includes implementing a partial correction
24 step to compensate for measurement error;

25 wherein implementing the partial correction step to compensate for
26 measurement error is supplemented by using a weighted least squares
27 regression to emphasize more reliable measurements with respect to less
28 reliable measurements;

29 h) integrating the quaternion error estimate;

30 i) normalizing the integrated quaternion error estimate to produce a
31 new estimated sensor orientation quaternion; and

32 j) repeating steps a)-j), wherein the new estimated sensor
33 orientation quaternion is used for e), calculating a computed measurement
34 vector.

1 Claim 30 (withdrawn): The method of Claim 23 wherein the operation of g),
2 performing a mathematical operation that results in the minimization of the
3 criterion function and outputs a 4x1 quaternion error estimate includes:

4 measuring an angular velocity of the sensor to generate an angular rate
5 quaternion;

6 integrating the angular rate quaternion;

7 normalizing the integrated angular rate quaternion to produce an
8 estimate of sensor orientation quaternion derived from the angular rate
9 quaternion; and

10 using the estimate of sensor orientation quaternion derived from the
11 angular rate quaternion to correct for time lag.

1 Claim 31 (withdrawn): A sensor apparatus comprising:

2 a magnetic field detector configured to measure a magnetic field vector
3 and output a local magnetic field vector signal; and
4 an acceleration detector configured to detect a local gravitational field
5 vector and output a local gravitational field vector signal.

1 Claim 32 (withdrawn): The sensor of Claim 31, further includes an angular
2 velocity detector configured to detect an angular velocity vector of the sensor
3 and output angular velocity signal.

1 Claim 33 (withdrawn): The sensor of Claim 32 wherein, the angular rate
2 detector comprises a three-axis angular velocity detector; the magnetic field
3 detector comprises a three-axis magnetometer; and the acceleration detector
4 comprises a three-axis accelerometer.

1 Claim 34 (withdrawn): The sensor of Claim 31 wherein the sensor includes at
2 least one processor that receives and processes the signals from the magnetic
3 field detector and the acceleration detector to determine the orientation of the
4 sensor apparatus.

1 Claim 35 (withdrawn): The sensor of Claim 32 wherein the sensor includes at
2 least one processor that receives and processes the signals from the magnetic
3 field detector, the acceleration detector, and the signal from the angular
4 velocity detector, wherein the at least one processor is configured to
5 determine the orientation of the sensor.

1 Claim 36 (withdrawn): A system for tracking the posture and orientation of
2 body, the system comprising:
3 the body having mounted thereon at least one sensor;
4 each sensor including a magnetometer for measuring a magnetic field
5 vector and a acceleration detector for measuring a body acceleration vector,
6 and
7 at least one processor for receiving input from the magnetometer and

8 acceleration detector and using said input to calculate a local magnetic field
9 vector and a local gravity vector and to determine the orientation of the body.

1 Claim 37 (withdrawn): A system as in Claim 36 wherein the at least one
2 processor is configured input the body orientation information into a synthetic
3 environment; and

4 wherein the system further includes a display for displaying the
5 position and orientation of the body with respect to the synthetic environment.

1 Claim 38 (withdrawn): A system as in Claim 37 wherein the at least one
2 processor is configured to correct for the offset between sensor coordinates
3 and body coordinates.

1 Claim 39 (withdrawn): A system as in Claim 36 wherein each sensor further
2 includes an angular velocity detector for measuring a body angular velocity
3 vector.

1 Claim 40 (withdrawn): A system as in Claim 39 wherein the at least one
2 processing is configured input the body orientation information into a
3 synthetic environment; and
4 wherein the system further includes a display for displaying the
5 position and orientation of the body with respect to the synthetic environment.

1 Claim 41 (withdrawn): A system as in Claim 40 wherein the at least one
2 processor is configured to correct for the offset between sensor coordinates
3 and body coordinates.

1 Claim 42 (withdrawn): A system as in Claim 36 wherein the body comprises
2 an articulated rigid body having a plurality of segments interconnected by at
3 least one joint and wherein each segment has mounted thereon at least one
4 sensor.

1 Claim 43 (withdrawn): A system as in Claim 39 wherein the body comprises
2 an articulated rigid body having a plurality of segments interconnected by at
3 least one joint and wherein each segment has mounted thereon at least one
4 sensor.

1 Claim 44 (withdrawn): A method of determining the direction of a local
2 gravity vector with an acceleration detector, the method comprising:
3 moving the acceleration detector from a start point to an end point over
4 a time period;
5 taking measurements of the total acceleration vector during the time
6 period;
7 weighted summing the measurements of the total acceleration vector
8 over the time period; and
9 calculating gravity vector values using the weighted sum of the total
10 acceleration measurements.

ADDED NEW CLAIMS

1 Claim 45 (new): A method of tracking the orientation of a sensor, the method
2 comprising:

3 a) measuring a magnetic field vector to generate local magnetic field
4 vector values;

5 b) measuring an acceleration vector to generate local gravity vector
6 values;

7 c) determining a measurement vector from the local magnetic field vector
8 values and the local gravity vector values;

9 d) calculating a computed measurement vector from the estimate of sensor
10 orientation

11 e) comparing the measurement vector with the computed measurement
12 vector to generate an error vector that defines a criterion function; and

13 f) performing a mathematical operation that results in the minimization of
14 the criterion function using reduced order Gauss-Newton iteration.

1 Claim 46 (new). A method of tracking as in Claim 45 wherein the reduced
2 order Gauss-Newton iteration of Claim I takes into account that there are only
3 three independent elements in a quaternion.

1 Claim 47 (new). A method of tracking as in Claim 45 wherein the reduced
2 order Gauss-Newton iteration requires the inversion of a matrix with a
3 dimensionality of no more than 3 x 3.

1 Claim 48 (new). A method of tracking as in Claim 45 wherein the reduced
2 order Gauss-Newton iteration utilizes a reduced order 6 x 3X matrix entirely
3 composed of elements of the computed measurement vector.

1 Claim 49 (new). A method of tracking the orientation of a body limb segment
2 of a tracked subject compared to sensor orientation, comprising:

3 a) determining a correction to compensate for the difference

4 between sensor coordinates and body limb segment coordinates;

5 b) placing the tracked subject in a single predetermined reference
6 position;

7 c) wherein the body limb segment axes are aligned with
8 corresponding Earth-fixed axes or differ by a known offset; and

9 d) wherein the correction found while the tracked subject is in the
10 predetermined reference position consists of the inverse of the
11 orientation reported by the sensor and the inverse of any known
12 offset.

Allowance and passage to issue at an early date are respectfully requested.

Respectfully submitted,

ERIC R. BACHMANN
ROBERT B. McGHEE
XIAOPING YUN
MICHAEL J. ZYDA
DOUGLAS L. McKINNEY

Date: April 8, 2004

By: Donald E. Lincoln
DONALD E. LINCOLN
Attorney for Applicants
Registry No. 34,213
Phone: (831) 656-3356

Superintendent
Naval Postgraduate School
Office of Counsel, Code 00C
1 University Circle, Rm 131
Monterey, CA 93943-5001
(831) 656-3356